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CONSTRUCTION AND OPERATION OF A COMPACT FINE-WIRE PSYCHROMETER

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ABSTRACT

The construction and use of a fine-wire, unaspirated thermocouple-psychrometer capable of sensing rapid fluctuations in air temperature and relative humidity within plant canopies is discussed. Maximum depression of the wet sensor is achieved at windspeeds greater than 36 cm. sec.$^{-1}$ (0.8 m.p.h.). Under still-air conditions (0 cm. sec.$^{-1}$), estimates of relative humidity exceeded true values by 1 to 4 percent relative humidity. The use of a radiation shield was found necessary to reduce errors due to radiative heating of the sensors. A convenient means of periodically cleaning the wet-sensor wick is discussed.

Precise determinations of atmospheric humidity in the immediate microenvironment of a plant may be complicated and ill-defined by the instrument used. Standard humidity-sensing instruments, such as the hair-hygrometer or the somewhat more compact aspirated mercury-in-glass thermometer- and thermistor-psychrometers, have large sensors and bulky dimensions that grossly influence the microenvironment. These instruments only sample the average humidity in several air layers and have rather slow response times to fluctuating humidity conditions. Also, the artificially aspirated psychrometers seriously disturb the air layer in which the desired measurements are being made.

The instrument discussed in this paper was originally designed and built as part of a larger study of the physiological responses of plants to changes in the immediate microenvironment. This instrument is a small, compact, unaspirated thermocouple psychrometer capable of sensing rapid fluctuations of humidity within the canopy of growing plants. Originally, this instrument was designed to measure the humidity in the air layers near plant surfaces to facilitate estimates of the vapor pressure gradient between the plant and the surrounding air mass.

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A large number of unaspirated thermoelectric-psychrometers have been developed to measure atmospheric humidity with a minimum of disturbance to the microenvironment (Bellaire and Anderson 1951, Swinbank 1951, Raschke 1954, Berger-Landefeldt 1955, McIlroy 1955, Long 1957, and Caldwell and Caldwell 1970). Typically, these instruments basically consist of two small thermocouple or thermistor elements; one of these is dry and senses the air temperature, the other is kept moist with water and senses the "wet bulb" temperature. In most cases, these instruments can provide continuous measurements of humidity that can either be read instantaneously or recorded at some distance from the sensors.

The principal difficulty encountered in using unaspirated psychrometric instruments is the need for providing an optimum quantity of water to the wet element while allowing for maximum evaporative cooling of the sensor. In addition, the evaporation process and the resultant cooling of the air immediately adjacent to the wet element must not influence the response of the dry element. During measurements, it is assumed: that a steady state of relative humidity exists, that the heat required to vaporize water from the wet element is supplied by the air flowing over the sensor, and that the rate of evaporation is a function of the vapor pressure gradient between the sensor and the air. Therefore, for an unaspirated wet sensor to achieve maximum cooling for any given vapor pressure deficit, convective heat transfer must be sufficient to maintain the vapor pressure gradient, hence, maximum evaporation. These criteria can be met by using sufficiently small sensing elements wherein convective heat loss increases with a decrease in element size. A second advantage of very small elements is that the error due to absorption of shortwave radiation decreases with a reduction in size. The theoretical aspects of sensor size and convective transfer of heat, together with design criteria, are discussed in greater detail by Platt and Griffiths (1964) and Powell (1936)

METHODS

The compact thermocouple-psychrometer consists of two copper-constantan thermocouple sensing elements, which are attached directly to a water reservoir constructed of stainless steel tubing (fig. 1). The dry sensor (1) is mounted about 1 cm. above the wet sensor (2). Both sensors are constructed of 0.0076-cm. (0.003-inch) diameter copper-constantan wire. The junctions of both sensors were made by twisting the two thermocouple wires, soldering them together by using a high-grade silver solder, then trimming them to a junction length of 0.5 mm. The copper and constantan wires of the two thermocouples were trimmed to a length of 1 cm. Then, each junction was silver-soldered to the ends of 24-gage insulated thermocouple lead wires (3), which extend through a rubber stopper (4) in the end of the stainless steel tube (1 cm. diameter and 20 cm. long) water reservoir (5).

The wet junction is kept moist by means of a three-strand cotton thread wick (6) that extends from the water reservoir, through the rubber stopper, along the fine copper wire, over the junction, and to about 1 cm. beyond the junction. These design criteria, first discussed by Powell (1936), may be used to minimize the conduction of heat to the sensor along highly conductive copper wire. The individual strands of the wick can be separated so that the copper wire and junction can be inserted among them. Then the strands can be twisted together again. Construction of the wick assembly and provision of an optimum rate of water flow are the most critical and difficult aspects to consider in constructing a psychrometer. Trial-and-error adjustments are required to achieve the optimum rate of water flow, particularly as this is influenced by wick length and evaporating conditions of the environment.

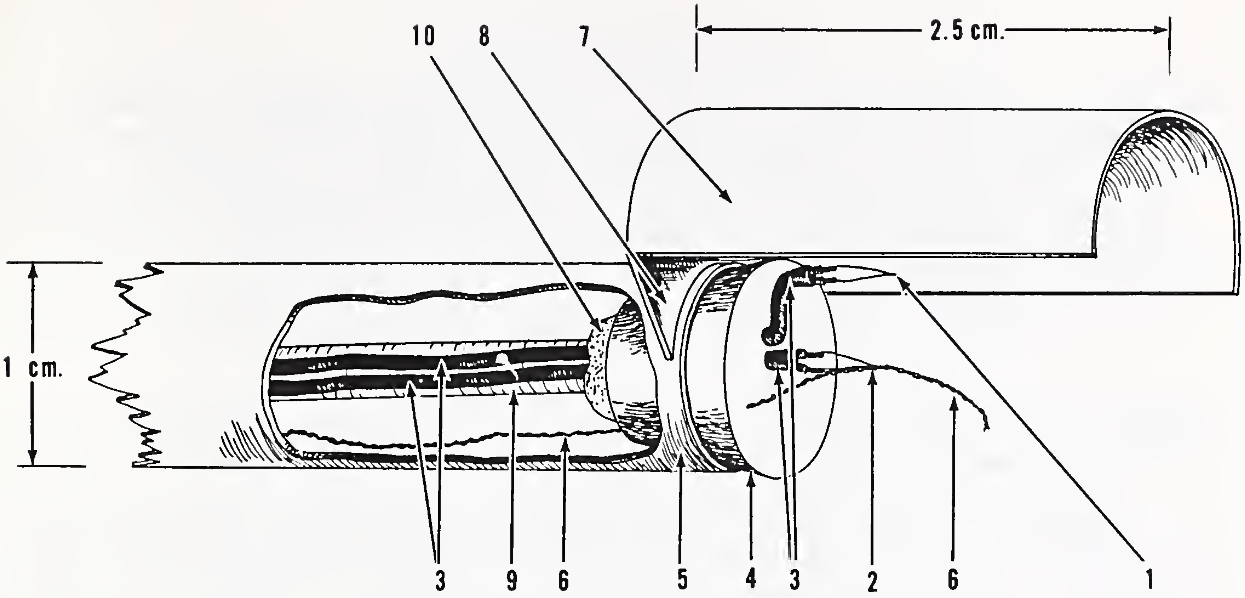

Figure 1.--Schematic of the fine-wire psychrometer showing: (1) dry sensor, (2) wet sensor, (3) insulated 24-gage thermocouple lead wires, (4) rubber stopper, (5) water reservoir, (6) cotton thread wick, (7) radiation shield, (8) radiation shield bracket, (9) plastic tube, (10) epoxy cement.

A radiation shield (7) is used to reduce sensor errors caused by direct incident solar radiation. The shield is constructed of polished, lightweight stainless steel (2.5 $cm.^2$) bent to form an arc with a 2 cm. diameter. The shield is soldered to a bracket 0.5 cm. high (8), which is also soldered to the stainless steel tube. It is advisable to place the sensing junctions below the level of curvature of the shield to avoid interference with natural convection.

The insulated thermocouple lead wires (3) extend through the rubber stopper (4), back into the water reservoir tube, and out the other end. Behind the rubber stopper and within the water reservoir, these lead wires are enclosed in a plastic tube (9) to prevent deterioration and corrosion. The plastic tube is cemented to the rubber stopper with epoxy cement (10). At the opposite end of the water reservoir tube, the lead wires and the plastic tubing extend through the rubber stopper used to seal the end of the reservoir. Water can be added to the reservoir periodically by removing the stopper and injecting water through a hypodermic syringe. The lead wires should extend at least 1 m. beyond the reservoir to prevent disturbances to the environment when measurements are made.

When the psychrometer is not being used or is being moved, the sensor end of the psychrometer is enclosed within a plastic vial to prevent sensor damage and to maintain a clean wick. A No. 6 rubber stopper, that has a hole 1 cm. in diameter through its center, is slipped over the water reservoir tube up to the radiation shield. The vial can then be slipped onto the stopper.

RESULTS AND DISCUSSION

The influence of windspeed on the temperature depression of the wet sensor below that of the dry sensor and the effect of shortwave solar radiation on sensor output were of primary concern. The influence of windspeed on the psychrometer performance was tested under carefully controlled conditions in a growth chamber. A small wind tunnel containing a rheostat-controlled fan was used and airflow rate was measured by a hot wire anemometer (Hastings RB - 1[2] omnidirectional probe). The thermocouple-psychrometer outputs were measured with a temperature potentiometer (Leeds and Northrup Co., No. 8692), and compared with values taken from an Assmann aspirated psychrometer (Wilk Lambrecht Co., Type 761).

The effect of windspeed on the response of the wet sensor under different relative humidities is summarized in table 1. These data show that for the range of environmental conditions studied maximum depression of the wet sensor response is reached at windspeeds greater than 36 cm. sec.$^{-1}$ (0.8 m.p.h.). The only significant errors in depression of the wet sensor response were recorded in still air, a phenomenon rarely observed under field conditions. At a windspeed of 23 cm. sec.$^{-1}$ (about 0.5 m.p.h.), the computed value of relative humidity would be about 1 to 2 percent too high and at 0 cm. sec.$^{-1}$, the value would exceed true relative humidity by 1 to 4 percent. Thus, calculations of vapor pressure gradients from relative humidity data gathered by using this psychrometer in the field or in a growth chamber will be quite accurate.

Table 1.-- *The influence of windspeed on wet sensor temperature depression under different relative humidities. Air temperature was 21° C. Values represent °C. above the Assmann psychrometer response*

Windspeed (cm. sec.$^{-1}$)	Relative humidity (%)		
	58	40	28
90	0	0	0
45	0	0	0
36	+0.2	+0.2	+0.2
23	+0.4	+0.3	+0.2
0	+0.5	--	+1.2

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[2] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others which may be suitable.

The importance of the radiation shield was illustrated by the effect of direct solar radiation on the sensors. With a radiation load of 1.2 cal. cm.$^{-2}$ min.$^{-1}$(measured by a Star pyranometer) and at a windspeed of 45 cm. sec.$^{-1}$, the unshielded dry sensor output exceeded the ambient air temperature by 1° C.; the unshielded wet sensor was 2° C. above the true wet bulb temperature. Errors of this magnitude under average conditions would lead to high estimates of relative humidity, exceeding the true values by 5 to 10 percent. However, when the sensors are shaded with the stainless steel radiation shield (fig. 1), accurate measurements of temperature and relative humidity can be made. Reflected shortwave radiation (albedo) from plant and soil surfaces does not influence the sensors sufficiently to affect their output. However, albedo from a highly reflective surface, such as snow, may require use of a lower shield as well.

This psychrometer has been used extensively in a controlled-environment growth chamber to measure the relative humidity of the air within the canopies of growing plants (fig. 2). Although only a limited amount of experience has been gained from its use in the field, the psychrometer appears well adapted for this purpose. Psychrometers of this design could easily be used to measure the relative humidity profile above the soil surface by stacking them on a mast at different heights. A dual-channel recording potentiometer, equipped with a temperature compensator, would provide for continuous recordings of both dry and wet sensors. Normally, the water reservoir will maintain adequate moisture for a period of about 2 or 3 days, but the reservoir could be easily enlarged during construction. The wick can be easily cleaned periodically by dipping the entire sensor-end of the psychrometer into boiling water containing a mild detergent and then dipping it in boiling distilled water.

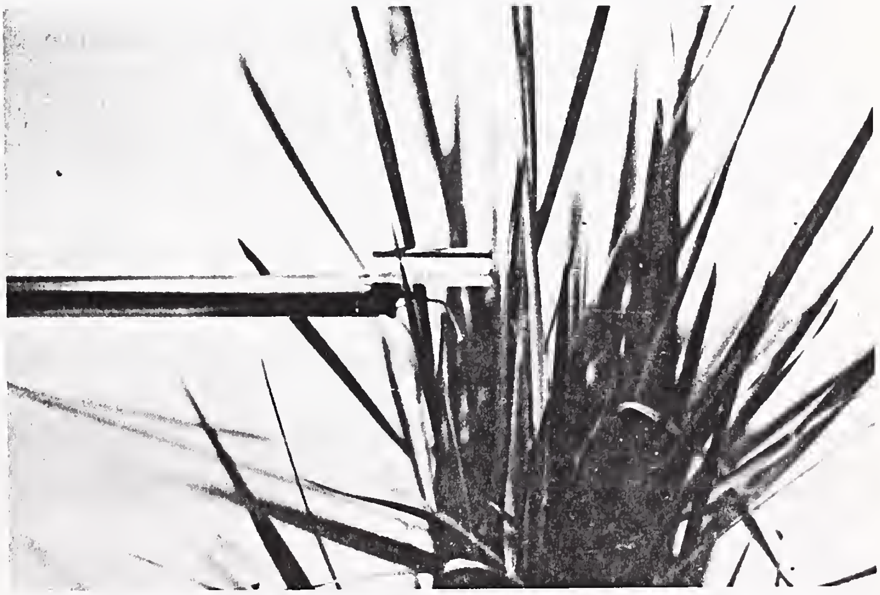

Figure 2.--The fine-wire psychrometer can be used in controlled-environment growth chambers, or in the field, to measure the relative humidity of the air within the canopies of growing plants.

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